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# The Use of Measurement Data to Analyse the Performance of Rooftop Diffraction and Foliage Loss Algorithms in a 3-D Integrated Urban/Rural Propagation Model.

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**Abstract:** This paper describes a 3-D integrated propagation model, which considers propagation effects in both urban and rural environments. It uses a variable resolution Digital Terrain Map (DTM) as well as building and foliage databases. Scattering off terrain pixels and building walls is modelled, as are off-axis terrain and rooftop diffraction contributions. The scattered power is estimated from radar cross-section analysis of the illuminated pixels and walls. The effects of foliage attenuation are also fully considered. The model predicts signal strength and time dispersion and provides fading and arrival angle information for the propagation channel.

Narrowband measurements in both urban and rural areas show very good agreement with the predicted results. The accuracy of different foliage-loss and diffraction-loss models has been assessed, with the ITU-R foliage-loss model and the UTD model giving the best results. It is shown that large errors can result if the effects of foliage are ignored in the modelling process.

## I. INTRODUCTION

Cochannel interference is one of the major causes of signal quality degradation in cellular radio links, and the challenge to the network planner is to deploy the network in a manner that maximises the carrier to interference ratio (C/I) for each cell. To this end, most planners make use of computer propagation prediction models, which predict signal strength in the radio environment.

Recently, considerable effort has been invested in developing propagation prediction models for both micro and macrocellular environments ([1],[2],[3],[4],[5]). Whereas the microcellular models tend to only consider small urban areas with buildings and flat terrain, the macrocellular models consider rural areas with variable terrain height but no specific buildings. Also most current prediction models are suitable for either dense urban (microcellular) or rural (macrocellular) environments. However, macrocells and microcells will tend to exist alongside each other (e.g. umbrella cells and multi-tier or hierarchical cell structures [6]) and it is vital in network planning to determine the interference effects from one cell type to the other. As such, prediction models which integrate propagation in both types of environments need to be developed to meet the needs of third generation planning.

The presence of foliage in the propagation channel can lead to severe signal attenuation ([7]), and thus the effects of vegetation in the propagation environment need to be considered in any prediction model. In addition, wave propagation from base station (BS) to mobile station (MS) is not restricted to the vertical Tx-Rx plane but includes scattered paths off this plane. This necessitates a 3-D approach to modelling in order to accurately predict signal strength, as well as characterising the time dispersive nature of the channel. Also, to accommodate the growing requirement for spatial information, prediction models need to provide arrival angles at the base and mobile stations.

This paper describes an integrated 3-D model, which combines the key features from previous urban and rural models. Thus it models large areas with irregular terrain but can also consider the effects of individual buildings as well as foliage. Microcell models generally assume the BS to be below rooftop height and power flows to the MS in the horizontal plane via multi-reflection and corner diffraction. However, when the BS is above rooftop height power tends to flow in the vertical plane, and rooftop diffraction and terrain and building scatter dominate. This model considers the latter case and is optimised for high-mounted BS interference and coverage in urban and rural areas. The model is also useful for interference between low mounted BS microcells where most propagation occurs in the vertical plane and results from rooftop diffraction. For efficient low-mounted BS microcell coverage a ray-tracing model such as [5] is recommended, which is optimised for analysis in the horizontal plane.

In this paper, narrowband measurements have been used to validate and optimise the performance of the model. The accuracy of different foliage loss and diffraction models has been investigated to determine the most appropriate choice for this application.

## II. PROPAGATION MODEL

### A. FEATURES

The propagation model is an extension of that described in [7]. It is a fully 3-D deterministic model which uses a variable resolution Digital Terrain Map (DTM) in addition to a 3-D raster buildings database and a vector foliage database.

The DTM contains 50m resolution raster terrain elevation data with the resolution increased to 10m in built-up areas. A buildings database consisting of three-dimensional raster cells with 10m resolution is then superimposed on to the variable resolution DTM. Each isolated building is modelled as a solid polygon of a specified height, and contributes 5 scattering surfaces, corresponding to the walls and roof of the building.

The model considers full 3-D off-axis scattered paths from building walls and terrain pixels. It further considers terrain and rooftop diffraction and combinations of off-axis diffracted and scattered paths. The scattered power is estimated from the radar cross-section of the illuminated walls and terrain pixels. Only first order scattering is considered in the current implementation of the model.

For large prediction areas, the terrain database is divided into 3 zones bounded by 3 confocal ellipses with the BS and MS at the foci. The inner, middle and outer zones have terrain resolutions of 50m, 100m, and 200m respectively. The sizes of the ellipses are specified prior to each run as part of the input parameters to the program. Buildings are only considered in the innermost zone as the effects of buildings are deemed to be most significant in the vicinity of the BS and MS. Also, the maximum diffraction order in each zone is set by the user, and is usually highest in the innermost zone and lowest in the outer zone. This approach is illustrated in Fig. 1.

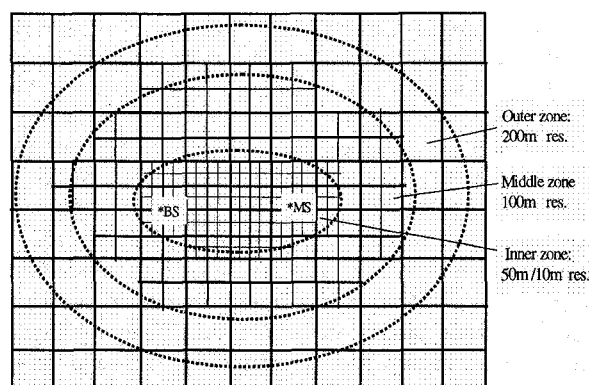


Fig. 1: Variable resolution approach for large areas.

## B: DIFFRACTION MODELLING.

To determine diffraction losses, path profiles from each illuminated pixel to the BS and MS are reconstructed, taking into account the variable resolution nature of the database. Paths with more diffraction edges than the maximum diffraction order in the corresponding zone are ignored.

In order to investigate the accuracy of various diffraction loss models, the user is offered a choice of 3 models: the Epstein-Peterson knife-edge model [8], the Picquenard knife-edge model [9], and the uniform Geometric Theory of Diffraction (UTD) model [10]. Comparisons between these approaches are presented in Section IV.

## C. FOLIAGE ATTENUATION

The model also makes use of a foliage database, which is a 3-D vector database of hedges and tree canopies.

For each propagation path, the total distance travelled within the foliage is computed. Again a choice of 2 empirical models for estimating the foliage attenuation is offered: the ITU-Recommended model [11] and the COST235 model [12]. Both models are equations derived from measurements, which relate the frequency and the distance travelled within foliage to the power loss in dB.

For the ITU-R model,

$$Loss = 0.2 * f(MHz)^{0.3} * d(m)^{0.6} dB \quad (1)$$

For the COST 235 model:

$$(a) Loss = 26.6 * f(MHz)^{-0.2} * d(m)^{0.5} dB \quad (2)$$

for vegetation OUT OF leaf, and

$$(b) Loss = 15.6 * f(MHz)^{-0.009} * d(m)^{0.26} dB \quad (3)$$

for vegetation IN leaf.

where  $f$  and  $d$  are respectively the frequency and distance travelled within foliage.

Other foliage loss models (e.g. [13] and [14]) require a much more detailed description of the foliage, and would have led to unreasonably large data storage for the terrain sizes being considered (up to 12km x 12km). Again, comparisons between both foliage loss models and measurements have been made and are presented in Section IV.

## D. MODEL OUTPUT

In addition to signal strength, the model also predicts time dispersion (complex impulse response and delay spread, coherence bandwidth), fast fading in the channel (Rician K-factor) as well as arrival angles at the BS and MS. Predictions are made for single mobile stations, multiple mobile stations (randomly located or along a specified route) as well as for specified grid areas (coverage maps).

Fig. 2 shows a sample output of the model for specified BS and MS locations.

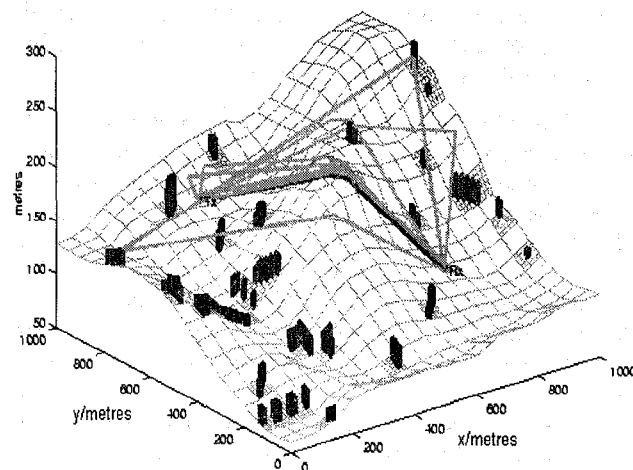


Fig. 2: Variable Resolution DTM with 10 strongest rays from TX (BS) to RX (MS).

It illustrates the 3D variable resolution terrain database (with buildings) for a 1Km x 1Km area, and shows the 10 strongest ray paths from the BS (TX) to the MS (RX). It also illustrates the full 3D off-axis scattering (off terrain and building walls), rooftop and terrain diffraction, as well as combinations of diffraction and off-axis scatter, implemented in the model.

Fig. 3 shows an example of a predicted coverage map for a 1Km x 1Km area of Bristol City centre, with 10m-grid point spacing.

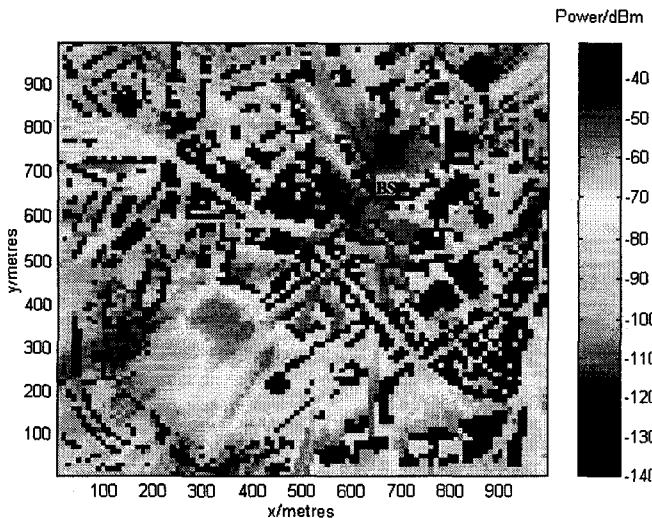


Fig. 3: Predicted coverage map for Bristol City Centre.

### III. MEASUREMENTS

Narrowband (or power) measurements have been made (at 1823MHz) in both urban and rural environments, for validating and fine-tuning the model. The rural macrocell measurements were made along a route with tall hedges on both sides of the road; these were presented in [7]. The urban measurements were carried out along several routes in Bristol City centre, an area with a fairly high building density, and with the BS antenna on top of a high building.

Fig. 4 shows a 3-D map of the vector building and foliage database around Bristol City centre.

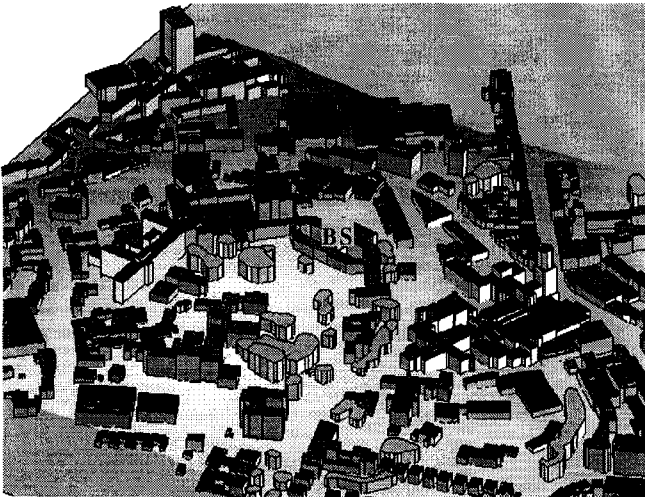


Fig. 4: 3-D map of Bristol City centre

Raster building data is obtained by vector-to-raster conversion of the vector building data.

Fig. 5a shows one of the measurement routes on a 2D view of the City centre. It also shows the raster building data around the route. Figure 5b shows the terrain variation along the route.

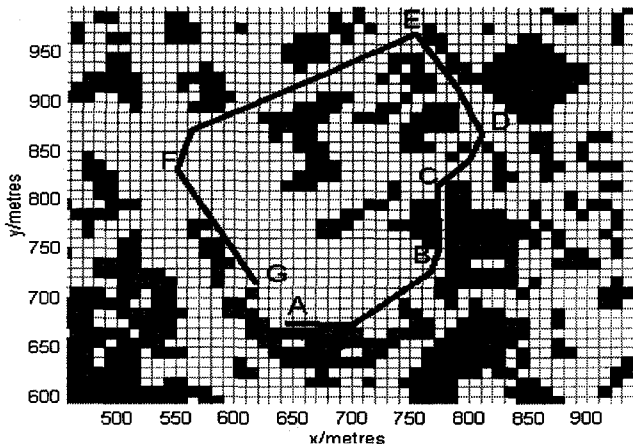


Fig. 5a: Narrowband Measurement Route

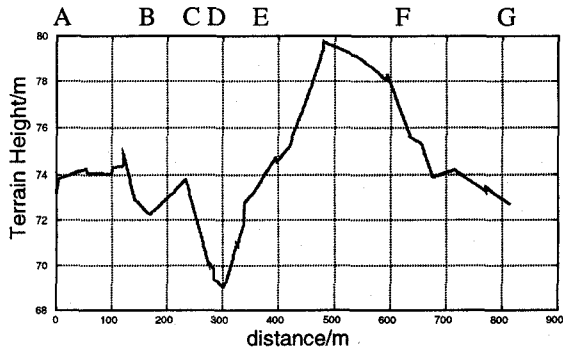


Fig. 5b: Terrain height variation along measurement route.

The measurements were made using a car Field Survey System with the MS antenna (dipole) mounted on the roof of the car (1.5m high). The BS antenna was also a dipole on a 20m high building, and the power transmitted at the antenna port was 33 dBm.

Fig. 6 shows the measured signal profile compared with the 3-D and 2-D model predictions for the measurement route above. These predictions used the ITU-R foliage-loss model and the UTD model.

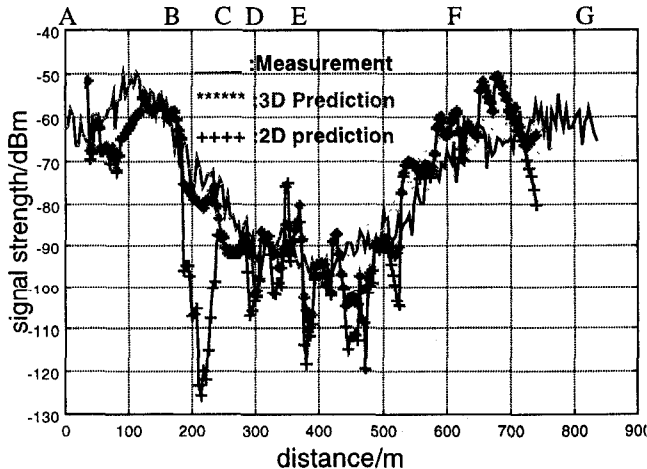


Fig. 6: Measured and predicted route profiles. VTC '98

Very good agreement is observed with the 3-D prediction (6.5dB rms. error), but problems exist when only the 2-D vertical plane model is considered. This is emphasised by the much higher rms. error (13.5dB). This is because of strong off-axis building and terrain scatter contributions to the overall signal strength along most of the route. Between 190m to 220m (B and C on Fig. 5) the route goes through a narrow street (10m wide) between 2 tall building blocks (each about 25m tall). With the MS being so close to the tall building, the rooftop diffraction loss is very high, and the dominant propagation mechanism in this case is via scattering off the opposite building walls. This accounts for the very high (40dB) difference between the 2D and 3D predictions along this section of the route.

## IV. SENSITIVITY ANALYSIS

### A. FOLIAGE-LOSS MODELS.

As mentioned earlier, the propagation model design offers a choice of foliage attenuation models. Using the narrowband measurements in Section III. A, the accuracy and applicability of these models has been assessed.

Fig. 8 shows a 2-D view of the foliage in the vicinity of the measurement route in Fig. 4.

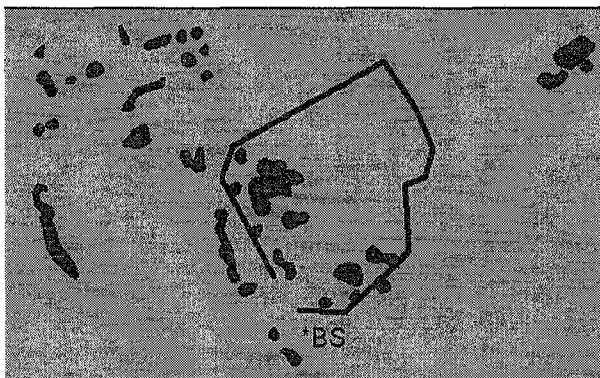


Fig. 8: Foliage database around measurement route

The model predictions using each of the 3 foliage loss models are shown in Fig. 9, together with the measured profile.

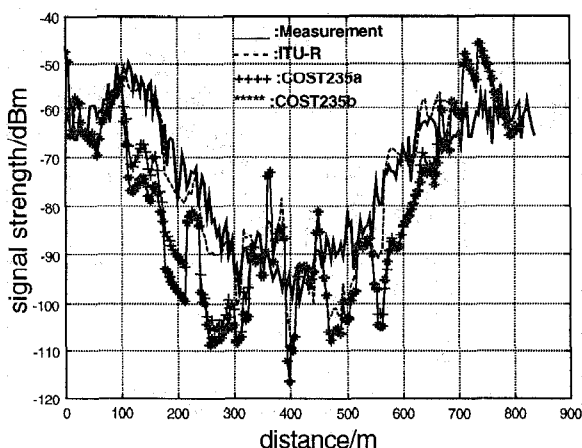


Fig. 9: Comparison between foliage-loss models.

The best agreement is obtained with the ITU-R model (6.5 dB rms. error) while both COST235 models tend to over-estimate the foliage loss (rms. errors of 12 dB for COST235a and 14dB for COST235b). The COST235b model for vegetation in leaf gives a higher error because the measurements were taken in winter, with most of the vegetation out of leaf. Also all the predictions used the UTD diffraction loss model for rooftop effects.

The impact of ignoring foliage attenuation is illustrated in Fig. 10.

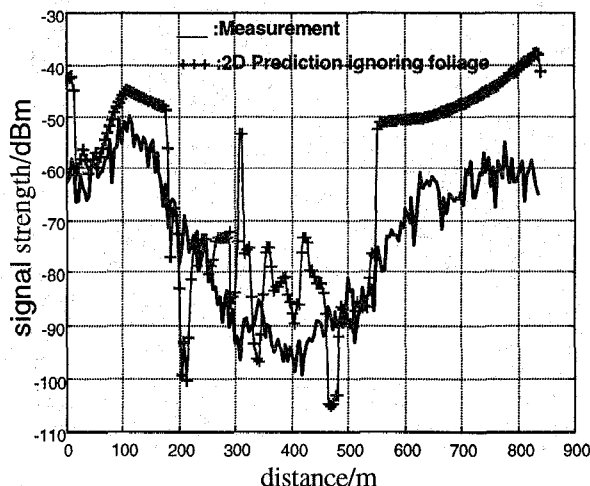


Fig. 10: 2D prediction ignoring foliage

The rms. error increases to 14.5dB for the 3D prediction and rises even further to 16dB with the 2D vertical plane model. Clearly, accurate foliage data is critical for modelling accurately in such areas and is a major cause of error. Ignoring such effects in a planning tool could certainly lead to poor quality of service in the network.

### B. DIFFRACTION-LOSS MODELS

Model predictions for the measurement route in Fig. 5 were obtained using the various diffraction models in section II.B. The results are illustrated in Fig. 11.

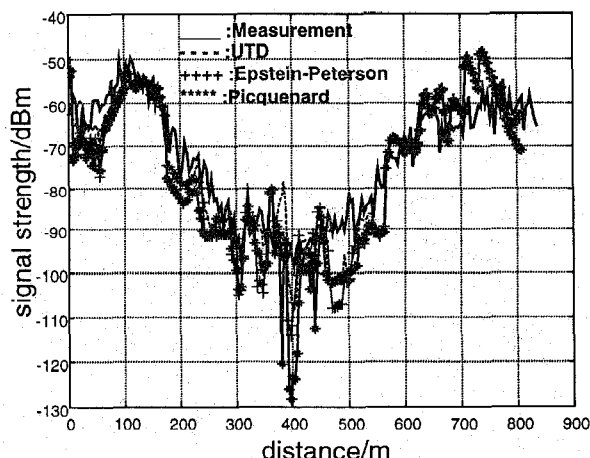


Fig. 11: Comparison between diffraction-loss models.

The UTD model performs best with an overall rms. error of 6.5dB compared to the knife-edge models (8 dB for

the Epstein-Peterson model and 9.5 dB for the Picquenard model). The differences are particularly apparent when more than 2 diffraction edges are encountered in the direct path between BS and MS (between 300m to 500m); in this case both knife-edge models tend to over estimate the diffraction loss. However, for single diffraction edges (600m to 800m), the accuracy of the knife-edge approach (particularly the Epstein-Peterson model) is comparable to that of the UTD model. Also both knife-edge models give very similar results with the Picquenard model slightly over-predicting the diffraction loss compared to the Epstein-Peterson model.

## V. CONCLUSION

An integrated propagation prediction model for urban and rural environments has been presented. The model supports full off-axis rooftop and terrain diffraction, combined scattering from buildings and terrain features, and combinations of these. The effects of foliage in the environment are also considered. It also features a novel variable resolution technique, which significantly speeds up the performance, particularly for large prediction areas.

Narrowband validation measurements give excellent agreement in both rural and urban environments (6.5dB rms. error). These have also highlighted the accuracy improvement of the 3-D analysis over the 2-D vertical plane approach. Further, the in-built flexibility of the model has allowed us to analyse the effects of different foliage-loss and diffraction-loss techniques currently available. The ITU-R foliage-loss model was found to give better accuracy over the seasonal-adjusted COST-235 model (6.5dB compared to 12dB rms. errors respectively). We have also shown that ignoring foliage attenuation in a propagation model will lead to large errors in some cases (up to 16dB rms. error in our example).

In our diffraction analysis, the UTD model was found to be more accurate than the simpler Picquenard and Epstein and Peterson knife-edge models for multiple diffracted paths (rms. errors of 6.5dB for UTD compared to 9.5dB for Picquenard and 8dB for Epstein-Peterson). The accuracy was however comparable for propagation paths with only a single diffraction order.

## VI. ACKNOWLEDGEMENTS

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